PREVALENCE AND COST OF CUMULATIVE INJURIES OVER TWO DECADES OF TECHNOLOGICAL ADVANCES: A LOOK AT UNDERGROUND COAL MINING IN THE U.S.

S. Moore, NIOSH, Pittsburgh, PA
E. Bauer, NIOSH, Pittsburgh, PA
L. Steiner, NIOSH, Pittsburgh, PA

Abstract

Technological advances in underground coal mining have led to a reduction in fatalities. This study demonstrated that the percentage of cumulative injuries remained largely unchanged across two decades of technological advances (1983-1984: 37%; 2003-2004: 33%). Furthermore, it was demonstrated that the average number of lost days due to cumulative injuries has increased (36±55 days and 62±82 days, respectively) which may have been due to the increased age of the work force or an increase in length of employment meaning that the mine workers injured in 2003-2004 had been exposed to ergonomic risk factors longer than those in 1983-1984. It is recommended that ergonomics processes be implemented as a means to systematically identify, prioritize, and resolve the root causes of these cumulative injuries.

Introduction

In the early 1900's as many as 3000 underground coal mine workers died annually. However, there has been a decreasing trend in mine worker fatalities. In fact, a low of 11 fatalities occurred in 2003 (1). This trend may be due to the fact that technological advances have provided for a safer work environment and have decreased the number of workers required to perform tasks. These technological advances have come in the form of machinery design, control, and operation.

Over the past two decades, foremost among these advances was the development of fan spray/scrubber systems on continuous mining machines and operation via remote control. This has allowed for increased productivity and has reduced the operator's exposure to whole body vibration. However, it has also resulted in exposure to a different ergonomic risk factor since manual tasks such as cable handling are now performed by the operator. A second important technological advance has been the incorporation of dual-boom bolting machines which increased the rate at which the roof could be bolted. In the past, one worker drilled holes and installed bolts while a helper assisted with the supply and bolt makeup tasks. However, now two workers perform all the bolting tasks individually (drilling, bolt makeup, supply, and installation). Thus, two workers are now exposed to a variety of ergonomic risk factors associated with these tasks. Finally, supply tasks have been mechanized with scoops to reduce the manual tasks performed by the supplymen, utilitymen, and laborers. However, there is still a great deal of exposure to ergonomic risk factors since there is a need for the manual unloading of supplies resulting in lifting, twisting, and awkward postures. Other ergonomic risk factors were also introduced with the changes in technology, such as pinch points, jolting, and jarring while operating scoops.

The primary concerns within the mining industry have been reducing fatalities, increasing production, the costs of equipment and replacement parts (2). While the technological advances in the mining industry may have positively affected workers' tasks and the efficiency of extracting coal, they may not have reduced cumulative injuries. Many jobs still expose mine workers to ergonomic risk factors such as awkward postures, exposure to whole body vibration, forceful exertions, and repetitive motions (2-5). In the early 1980's, sprains and strains alone were shown to account for approximately 20%-50% of all underground mining injuries (6).

These data suggest that, despite the vast improvements in technology, the prevalence of cumulative injuries in underground mining may have remained unchanged. Therefore, the drive towards design of tasks, equipment, and tools, as a means of reducing cumulative injuries may still be needed. However, some companies have chosen not to commit their resources to such an endeavor because a clear need/benefit has not been shown.

The objective of this study was to determine and compare the prevalence of cumulative injuries across two decades of technological advances (1983-1984 and 2003-2004) and to provide a means to make a general cost estimate for these injuries. Since the exposure of mine workers to risk factors as a whole has not been reduced, it was hypothesized that a difference in the percentage of cumulative injuries reported for 1983-1984 and 2003-2004 would not be observed. Additionally, differences in the incidence rate of injury, age of the mine workers injured, days lost, and length of employment at mining facilities were evaluated to allow for a more detailed comparison.

Methods

While some technological advances within the mining community have been rapidly employed by all mine companies, others have been slower to implement. Therefore, data was obtained from two different decades to ensure that nearly all mine operations now implemented the major technological advances. To increase the sample size and avoid a local minima or maxima in the database, two years were evaluated for both decades instead of just one. The Mining Safety and Health Administration (MSHA) injury databases were used for this study. All injuries listed in the MSHA databases for the calendar years of 1983 and for 1984 were combined to form the first data set which will be referred to as the 1983-1984 data set. Similarly, all injuries listed in the MSHA databases for the calendar years of 2003 and 2004 were combined to form the second data set which will be referred to as the 2003-2004 data set. Both the 1983-1984 and the 2003-2004 data sets were filtered such that only injuries occurring at underground coal operations were considered and the total number of underground coal injuries was then determined for each data set.

To determine the number of cumulative injuries for each data set, a previously reported algorithm was utilized (7). This algorithm identifies injuries that were cumulative in nature based on their "Nature of Injury" code. Cumulative injuries can be attributed to cumulative trauma or can be a reoccurring injury that was initially attributed to an acute trauma. Many injuries caused by an acute trauma result in a recurring injury; therefore, the methodology utilized in this paper assumes that regardless of whether the injury was initiated by a cumulative trauma or an acute trauma, it results in a cumulative injury. Under this assumption, the following injury codes were isolated: 260 (Hernia, rupture); 270 (Joint, tendon, or muscle inflammation or irritation); 330 (Sprain, strains); 370 (Multiple injuries); and 400 (Unclassified, not determined). Occasionally, injuries to the musculoskeletal system are classified in two other injury codes as well: 380 (Occupational diseases, NEC) and 390 (Other injury, NEC). However, many of the injuries classified under these two injury codes are not to the musculoskeletal system. Therefore, it was necessary to read the narratives of those injury records to ascertain whether or not the injury was to the musculoskeletal system. Using this algorithm, a total of 8,083 and 3,266 cumulative injuries were identified from 1983-1984 and 2003-2004 databases, respectively.

For the 1983-1984 and 2003-2004 data sets, the number and percentage of cumulative injuries, with respect to the total number of injuries reported, was determined for underground coal. The days lost due to the injury and the associated incidence rates (normalized to 200,000 hours worked; Equation—1) were then computed (mean±SD) for both sets of data. The total hours worked included surface and underground mine workers at underground coal mines including both bituminous and anthracite operations. For the 1983-1984 and 2003-2004 data sets, the average age of the mine workers that experienced cumulative injuries, and their average length of employment in mining, was then determined. For both data sets, the cumulative injuries were then further sub-divided by the part of body injured (e.g. back, knee, arm/shoulder). The body parts included in the analyses were the ankle (MSHA data base code: 520), arm/shoulder (MSHA data base codes: 310, 311, 313, 314, 450), knee (MSHA data base code: 512), back (MSHA data base code: 420), and neck (MSHA data base code: 200). The costs of cumulative injuries, by body part, are also presented based on data from the National Safety Council (8). (**Table 1**) The manner in which the National Safety Council reported these data has changed over the decades, and; therefore, a direct comparison between the 1983-1984 and 2003-2004 data sets is not possible. It should be noted that the cost data provided by the National Safety Council are not specifically for cumulative injuries. Rather, the cost data pertains to all types of injuries to these body parts.

$$IncidenceRate = \frac{(\text{Total \# Injuries} * 200{,}000\text{hrs})}{\text{Total Hours Worked}} \qquad (1)$$

Table 1. Average Total Incurred Medical Costs Per Claim By Body Part.

Average Total Incurred Costs per Claim (by Body Part)	
Part of Body	**National Safety Council Injury Facts® 2004**
Ankle	$10,358
Arm/Shoulder	$16,564
Knee	$16,966
Lower Back	$17,738
Upper Back	$11,533
Neck	$23,862
Average	**$17,098 ± $4,793**

The total number of injuries decreased from 1983-1984 (21,792 total injuries) to 2003-2004 (10,046 total injuries) (**Table 2**). Cumulative injuries accounted for 8,083 and 3,266 for the 1983-1984 and the 2003-2004 data, respectfully. Thus, despite changes in technology, the percentage of cumulative injuries remained nearly unchanged between the two decades (37% and 33%, respectively). Additionally, there was only a small decrease in the incidence rate which dropped from 4.5 to 3.8 between the two decades, respectively.

Table 2. Break Down of Cumulative Injuries by Incidence Rate, Days Lost, Age, and Length of Employment.

	1983-1984	**2003-2004**
Total Number of Injuries	21792	10046
Total Number of Cumulative	8083	3266
Percentage of Injuries that were Cumulative	37%	33%
Incidence Rate of Cumulative	4.5	3.8
Average Days Lost for Cumulative Injuries	36±55	62±82
Average Age when Suffered Cumulative Injury	35±9	42±11
Average Years of Mining Experience when Suffered	10±6	16±11

When evaluating the average days lost for cumulative injuries, there were 11 injury records where this information was unknown for the 1983-1984 data. When excluding these injury records, it was found that in 2003-2004 the average days lost was higher, by 26 days, than in 1983-1984. This also corresponded to an increase in the average age of the mine workers that were injured.

The average age of the injured mine workers was calculated based on the date of birth entered into the MSHA database. Therefore, occasionally this information is entered incorrectly or not at all. For the 1983-1984 and 2003-2004 data sets, 307 and 64 injury records, respectively, were excluded due to missing information or ages that were likely incorrect (less than 17 years or greater than 75 years). Using the remaining injury records, it was found that in 2003-2004 the average age of the mine workers that suffered a cumulative injury increased by 7 years.

When evaluating the average length of employment of mine workers at the time they suffered a cumulative injury, missing data was encountered for 624 injury records in the 1983-1984 data set and 207 injury records in the 2003-2004 data set. For the remaining injury records, it was observed that mine workers suffering cumulative injuries in 2003-2004 had been employed 6 more years than those in 1983-1984.

These cumulative injuries were then evaluated with respect to body part (**Table 3**). It should be noted that for the 1983-1984 data, five injuries were listed as 'unclassified' for body part while two injuries were 'unclassified' for the 2003-2004 data. Thus, these injury records could not be included in this analysis. Cost estimates were made by comparing the number of injuries by body part to the data provided from the National Safety Council® in **Table 1**. For example, in 2003-2004, 569 cumulative injuries to the knee were reported. Thus, one could estimate that this resulted in a cost of $9,424,916, or $16,564 per knee injury. **Table 3** demonstrates that back injuries accounted for the largest percentage of cumulative injuries. While there was nearly a 10% drop in the percentage cumulative back injuries between the 1983-1984 and 2003-2004 data sets, there was also an increase of nearly 10% in the percentage of cumulative injuries to the knee between the two data sets (**Tables 2 and 3**).

Discussion

In this study the prevalence of cumulative injuries across two decades of technological advances (1983-1984 and 2003-2004) were compared and a means to make a general cost estimate for these injuries was provided. Additionally, differences in the incidence rate of injury, age of the miners injured, days lost, and length of employment at mining facilities were evaluated to allow for a more detailed comparison.

The data demonstrated that there was a decrease in the *number* of cumulative injuries between the two decades. This may have been due to the decrease in the average number of workers from 103,431 to 44,456 for 1983-1984 and 2003-2004, respectively (8). However, despite the decrease in the overall number of cumulative injuries, the *percentage* of cumulative injuries remained nearly unchanged (37% and 33%, between 1983-1984 and 2003-2004, respectively) since this difference was within the accuracy of the algorithm used to isolate cumulative injuries via the "Nature of Injury" code (7). Therefore, the hypothesis was supported. For both decades, a large percentage of cumulative injuries were reported which indicates a clear need to address these types of injuries. These data compare well with previous studies that have reported sprains and strains or other cumulative injuries to be a major contributor to injury rates (6).

Table 3. Break Down of the Number and Percentage of Injures, by Body Part, for Comparison with Average Costs for Injury (**Table 1**).

Number and Percentage of Cumulative Injuries (by Body Part)		
Part of Body	**1983-1984**	**2003-2004**
Ankle	376 (5%)	118 (4%)
Arm/Shoulder	355 (4%)	305 (9%)
Knee	752 (9%)	568 (17%)
Back	3348 (41%)	1031 (31%)
Neck	475 (6%)	192 (6%)
Average	**1062±1288 (13±16%)**	**43±371 (14±11%)**

There was only a small drop in the incidence rate of cumulative injuries, which was within the accuracy of the algorithm utilized to isolate the cumulative injuries. This indicates that the ratio of cumulative injuries to hours worked has remained largely unchanged as well. Thus, while technological advances may have increased production and decreased fatalities (1), cumulative injuries must still be addressed.

Several other interesting facts were also observed. In 2003-2004, a longer recovery time was required before mine workers could return to work, which was indicated by an increase in lost days of 68% when compared to the 1983-1984 data. This corresponded to the fact that the average age of the mine worker being injured was 7 years greater in 2003-2004 than in 1983-1984. Moreover, it also corresponded to an increase in length of employment. In fact, the mine workers that experienced cumulative injuries in 2003-2004, on average, were employed for 6 more years than those in 1983-1984. Previous research has reported that recovery periods for older workers are typically twice as long as those for younger workers (9). Therefore, the increase in lost days may have been due to aging effects and/or an increase in the length of employment. With an increase in length of employment comes prolonged exposure to risk factors. This has further been exacerbated by technological advances such as remote controls which have allowed for higher equipment utilization and reduced worker fatigue, but have also reduced breaks (11). This has resulted in an increase in the number of sequentially worked hours by a mine worker. Other confounding factors such as lifestyle changes, injuries outside the workplace, or a combination of several factors may have also played a role. Regardless of the root cause, increased recovery time plays a major role in the cost of cumulative injuries since finding replacement mine workers has become increasingly more difficult as there are not enough mine workers to meet this demand.

The data presented in this study also demonstrated that over 30% of cumulative injuries were to the back which has been shown to have recurrence rates of 70% to 80% (10). In the future, there may also be a reduction in seam heights across the underground coal mining industry as technology allows for this coal to be extracted more economically (11). This may increase the number of mine workers in low seam mines and may also increase their exposure to ergonomic risk factors associated with knee injuries (e.g. kneeling, crawling). This is a major concern since the cost of knee injuries was nearly identical to that for the back. At this time, tool and equipment design has been predominately focused on the cost of extracting coal since this has been the primary interest of their clients, the mine companies. Therefore, it is important to inform mine companies about the financial burden associated with equipment designs that do not fully complement the mine worker. Unless mine companies communicate with equipment manufactures about the importance of ergonomics in equipment design, future technology is likely to continue exposing mine workers to risk factors. In addition to equipment design changes, other factors may also be considered such as taking out extraneous matter to provide a working height that is larger than the seam height.

The results of this study clearly demonstrate the need to address the cost and prevalence of cumulative injuries. A proactive approach to this problem would be to implement an ergonomics process which would provide a systematic method to identify, prioritize, and resolve the root causes of cumulative injuries. Ergonomics processes have already been shown to be successful in industries other than mining (12, 13). In fact, ergonomics processes have even been implemented at some surface mines with the help of NIOSH personnel and are also showing signs of success (14). Many companies have been concerned with the resources necessary to implement an ergonomics processes; however, the resources required are often less than initially anticipated since it can frequently be integrated into already existing safety and health programs.

In the current study, only underground coal mining injuries were evaluated. However, for all mining, technological advances were primarily focused on reducing fatalities while increasing production. A limitation to this study was that the data presented was obtained from analyses of the MSHA database which is an "injury" database. Thus, when mine workers experience the initial symptoms of cumulative injuries they often are not reported. Therefore, the results in this study should be considered a lower bound. Having only injury data also did not allow incidence rates to be age-adjusted despite the fact that a substantial change in the age distribution of the population was noted between the two data sets evaluated. The data provided to perform a general cost should also be considered a lower bound since the estimate did not include indirect costs such as those associated with finding a replacement mine worker or training new and existing mine workers. Other indirect costs include: reduced efficiency/production, reduced quality, pain, and suffering. Additionally, estimates for both decades were generated using cost data for only one time period.

In the future, NIOSH intends to continue promoting and assisting mining companies in the implementation of ergonomics processes through web-based training and "train the trainer" guides which will also provide solutions to common problems. Also, when redesigning equipment to reduce injuries, it is important to understand how mine workers are being injured. Different design characteristics may be warranted if an injury was caused by repetition, excessive force or if it is a recurring injury that initially occurred due to acute trauma. Therefore, in the future, the authors intend to investigate differences in injuries that are cumulative in nature to those that may become cumulative following an initial acute trauma.

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Disclaimer

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